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Towards Biological Control of Salvinia in Papua New Guinea

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Abstract

The aquatic fern *Salvinia molesta* is causing major problems in > 500 km^2 of waterways in the Sepik River basin, Papua New Guinea. Approximately 1200 adult *Cyrtobagous salviniae* were introduced as biological control agents in 1982. Field establishment was achieved only when the nitrogen content of salvinia at the initial release site was raised by application of urea. Evidence was obtained that feeding damage caused by *C. salviniae* modifies the host plant in favour of the insect by raising nitrogen levels. A critical density of weevils may be required to trigger conditions favourable for a population explosion. *C. salviniae* is now well-established in the Sepik basin and some 500,000 adults had been distributed to 60 sites by mid-1984. The insect is most successful on thin, mobile weed mats and is already providing control in several lakes.

Lutte Biologique Contre Salvinia a Papua, en Nouvelle-Guinée

La fougère aquatique *Salvinia molesta* suscite de graves problèmes sur une superficie de plus de 500 km^2 du bassin de la rivière Sepik à Papua, en Nouvelle-Guinée. Environ 1200 adultes d'une espèce de charançon *Cyrtobagous salviniae,* ont été libérés comme agents de lutte biologique en 1982. Les insectes ne se sont établis que lorsque la teneur en azote des *Salvinia* dans le site initial d'introduction des insectes a été augmentée par l'application d'urée. D'après les observations, les dommages causés par *C. salviniae* entraînent une augmentation des concentrations d'azote de la plante hôte, ce qui favorise les insectes. Une certaine densité de charançons peut être critique pour créer des conditions favorables à une explosion de la population. *C. salviniae* est actuellement bien établi dans le bassin Sepik, et au cours des premiers mois de 1984, quelque 500,000 adultes ont été introduits en 60 sites. L'insecte réussit mieux sur les minces couches de plantes nuisibles mobiles et assure déjà une lutte efficace dans plusieurs lacs. Pour les couches de plantes nuisibles fortement colonisées par une végétation flottante secondaire, il sera peut-être nécessaire d'avoir recours à des méthodes de lutte intégrée, c'est-à-dire commencer par un traitement herbicide et ensuite introduire *C. salviniae,* pour empêcher la régénérescence de *S. molesta.*

Introduction

Salvinia molesta D.S. Mitchell (Salviniaceae) is a free-floating aquatic fern which originated in S.E. Brazil (Forno and Harley 1979). Man has distributed the plant widely through the tropics and subtropics. The plant can double in weight, numbers of ramets and leaf area in as little as 2.2 days (Farrel 1979), and its ability to cover areas of still water rapidly has caused it to be regarded as one of the world's worst aquatic weeds.

The exact time and place of introduction of salvinia to Papua New Guinea (PNG) are not known. Recent oral history suggests that it was taken to the Sepik River from the nearby coastal town of Wewak in 1971–72. The Sepik River rises near the border between PNG and Irian Jaya and for most of its 1200 km course meanders west to east through a wide alluvial flood plain. In its middle and lower reaches, the river is up to 500 m wide and 35 m deep. Hundreds of oxbow and shallow depression lakes and lagoons are associated with the river. These vary in size from a few ha to the 250 km^2 Chambri Lake. Depending on their age, and degree of useage by local people, the lagoons may be connected to the mainstream by permanent or seasonal channels.

The lives of Sepik villagers centre on the use of these waterways for fishing, access to garden areas and sago palm swamps (the major carbohydrate source) and to more distant facilities such as markets, schools and hospitals. By forming thick floating mats, salvinia interferes with or prevents, movement of canoes and outboard-powered boats, seriously disrupting most aspects of traditional, subsistence lifestyles. In addition, the plant interferes with economic activities such as trade in crocodile skins and sale of artifacts to tourists. Mitchell (1979) and Thomas (1979) recommended, *inter alia*, that an integrated approach with biological control as the major component would provide the only economically viable long-term solution. In 1981 a joint UNDP/FAO/PNG Government project was set up to develop cost-effective management of salvinia in PNG.

By the end of 1980 the plant had spread through 500 km^2 of waterways with some 200 km^2 of water surface covered by weed mats. During 1981 one of us (Thomas) carried out trials with herbicides and the use of booms, while Room (1981) reported on the prospects for extending to PNG techniques for biological control of salvinia being developed in Australia. Although the short-term results of chemical control were spectacularly effective, regrowth from plants sheltered by marginal vegetation, and the consequent need for repetitive spraying made chemical control alone, an uneconomic proposition. Mechanical or physical control was found to have only limited application.

Control of salvinia on Lake Moondarra in central Queensland, Australia, was achieved in 1981 using a weevil, thought at the time to be *Cyrtobagous singularis* Hustache (Coleoptera: Curculionidae) (Room *et al.* 1981). Subsequent investigations (Sands 1983) showed the weevil to be a previously undescribed species, *Cyrtobagous salviniae* Calder & Sands (Calder and Sands 1985), and all subsequent references to *Cyrtobagous* in this paper are to this species. The biology and feeding habits of *Crytobagous* have been described by Forno *et al.* (1983) and Sands *et al.* (1984). Another insect, *Samea multiplicalis* (Guenée) (Lepidoptera: Pyralidae), had also been released in Australia (Room *et al.* 1984) but *Cyrtobagous* appeared to have greater potential and it was decided to import this insect into PNG first.

Introduction and Establishment of *Cyrtobagous salviniae*

The data summarised here are presented in detail in Room and Thomas (1985).

The first importation of *C. salviniae* into PNG consisted of 590 adults collected from Lake Julius, central Queensland, where the weevil had been established previously. The 50 ha Binatang Lagoon, 10 km east of Angoram (4.04°S 144.04°E) was selected for the first release. It was completely covered by salvinia and a few small sudd islands. However, in contrast to Lake Moondarra, the salvinia in Binatang Lagoon appeared yellowish, suggesting a nutrient deficiency. In February 1982, two 2 $\times$ 2 m floating cages, similar to those described by Room *et al.* (1981) were placed over salvinia in the lagoon and several days later, 285 adult *C. salviniae* were released into each cage. In an attempt to overcome the possible nutrient deficiency, a plastic bag containing 2 kg of NPK fertiliser was pierced in several places and hung just below the water surface in each cage. The bags were recharged on 3 June 1982.

No regular sampling was carried out as we wished to keep disturbance and removal of salvinia (and insects) to a minimum. There was little apparent damage to the salvinia in the cages by September 1982, despite there having been time for four generations of the insect since introduction (Forno *et al.* 1983).

Samples extracted with Berlese funnels (Boland and Room 1983) in early September suggested that there were only *c.* 20 adults in each cage, mostly concentrated around the bags of fertiliser. There was no evidence of predation or parasitism and comparison with a wide range of Australian release sites (Room *et al.* 1984) indicated that climatic factors were not likely to be limiting. Salvinia 30 m from the cages had a mean nitrogen content for the period February–September 1982 of 0.96% dry weight ($n = 24$). This contrasted with an average of 1.71% N ($n = 7$) in Lake Moondarra, where *C. salviniae* destroyed 80% of salvinia in similar cages in only seven months (Room *et al.* 1981).

Effects of Nitrogen on Weevil Populations

We suspected that establishment of the weevils in Binatang Lagoon was being hampered by low N levels. In late September 1982, therefore, a further 296 *C. salviniae* from Lake Julius and a second bag of NPK fertiliser were added to each cage. Additional N was supplied each week until mid-March 1983 by spraying 25 g urea in 200 ml water on the salvinia in each cage.

By mid-November, 1.5 generations later, 90% of salvinia buds in the cages had been damaged and Berlese funnel samples from the cages showed that the *C. salviniae* population had more than doubled. Over the next 6 wks, quantities of salvinia containing all stages of *C. salviniae* were removed from cages and placed just outside them. Fresh salvinia was placed inside the cages to ensure an adequate food supply for the remaining insects. Salvinia heavily damaged by *C. salviniae* turned dark green, suggesting high N levels, before turning brown and rotting. Average N content of salvinia inside the cages during fertilising was 1.75% ($n = 4$), in contrast to 1.10% ($n = 30$) 30 m from the cages.

To test the apparent effect of applying urea, a series of experiments was started in other Sepik lakes. *C. salviniae* was released onto salvinia receiving: (a) no fertiliser; (b) urea; and (c) urea + superphosphate. Developments were monitored weekly. Results to date, and results of similar experiments in Australia (Room *et al.* 1985), clearly indicate that raising the concentration of N in salvinia from $< 1\%$ to near 1.5% dry weight significantly increased the rate of *C. salviniae* reproduction. Conversely, applying superphosphate in addition to urea appeared to have no, or even a slight negative, effect.

Still further evidence for the importance of N content of salvinia to its biological control agents has been demonstrated by the studies of Sands *et al.* (1984) and Taylor (1984). These workers have shown that high levels of N cause faster development of larvae and increases in fecundity of both *C. salviniae* and *S. multiplicalis.*

Contrary to expectations, the population of *C. salviniae* in Binatang Lagoon continued to thrive as it slowly expanded away from the cages and the fertilised salvinia. In addition, regenerating salvinia was usually darker green than nearby, relatively undamaged material. This suggested that feeding by *C. salviniae* may modify the host plant to the insect's advantage. Destruction of buds precedes more extensive damage to older tissues. This may reduce competition for nutrients between surviving buds, while at the same time making more nutrients available from an increase in decaying plant material and insect frass.

Further evidence in support of this hypothesis came from two sources. In the fertiliser experiments, N levels in the control remained very similar to background N until emergence of the F_1 generation of *C. salviniae* produced a sudden increase in damage, whereupon N levels suddenly rose to the level in the +N and +NP treatments and remained at that level until just before the plant material died and sank (Fig. 1). In Binatang Lagoon (Fig. 2), tissue samples from heavily damaged plants close to the cages, consistently had higher N levels than relatively undamaged plants 30 m away. This trend continued until October–November 1983 when damage levels at 30 m became similar to those near the cages and the difference in N levels became much less pronounced.

In February 1983, 107 adult *C. salviniae* were extracted through Berlese funnels from 3 kg of salvinia from the cages and were released onto a thick salvinia mat on Gerehu Lake, near Port Moresby. The lake receives sewage effluent and provided an opportunity to assess the performance of *C. salviniae* under consistently higher N conditions than would normally be found in the Sepik.

Also in February 1983, 6 kg of salvinia containing *c.* 200 adult *C. salviniae* from the cages was placed among salvinia growing in seasonally flooded sago swamp adjacent to the channel connecting Binatang Lagoon to the Sepik River. This salvinia was exposed to silt-laden water flowing through the swamp at the peak of the flood season and could be expected to experience high nutrient levels. On 13 May 1983, a single sample of salvinia from the sago swamp contained 1.54% N compared with a routine sample, 30 m from the Binatang Lagoon cages, which contained 0.89% N. Patches of heavy *C. salviniae* damage and large numbers of adults were present in the sago swamp. These could only have developed from the insects released there in February and in only two generations the population density had far exceeded that in Binatang Lagoon.

Field Distribution of *Cyrtobagous salviniae*

The population explosion of insects in the sago swamp persisted from May until August when the last pockets of salvinia dried out with the falling flood level. During this period, some 100,000 adults and many more eggs, larvae and pupae were distributed to other lagoons in the Angoram area. Infested salvinia was placed in jute sacks and carried by boat to new sites in the Angoram area. A subsample of 2 kg was taken from each sack and *C. salviniae* were extracted using Berlese funnels to estimate the number of adults released at each site (generally 100–300 kg of salvinia containing 2000–12,000 adults). The live adults extracted from subsamples were flown to Ambunti, 150 km up river from Angoram, for release near the upstream limit of the salvinia infestation. Approximately 6000 adults were distributed in this fashion.

By November 1983, *C. salviniae* populations in lagoons near Angoram had developed sufficiently to allow further redistribution in the vicinity and *c.* 150,000 adults were moved to Ambunti by flying sacks of infested salvinia there for redistribution by boat. Attempts to drop infested salvinia into lagoons from a fixed-wing aircraft were unsatisfactory because the material spread over too wide an area. In response to radio appeals, a number of Sepik villagers carried infested salvinia back to their own lagoons.

By May 1984, some 500,000 adults had been distributed to 60 Sepik lagoons and establishment had been confirmed in half of these. The delay between release and what can be considered permanent establishment is not easy to assess with accuracy. In some lagoons assessment has been complicated by several releases being made at intervals and at other sites by the irregularity of visits. On Gerehu Lake, for example, the insects had multiplied sufficiently to cause discolouration of salvinia at the release site after $3\frac{1}{2}$ months. In the Sepik, four months elapsed between the earliest release on Imbuando Lagoon and the discovery of a widespread breeding population. Elsewhere in the Sepik

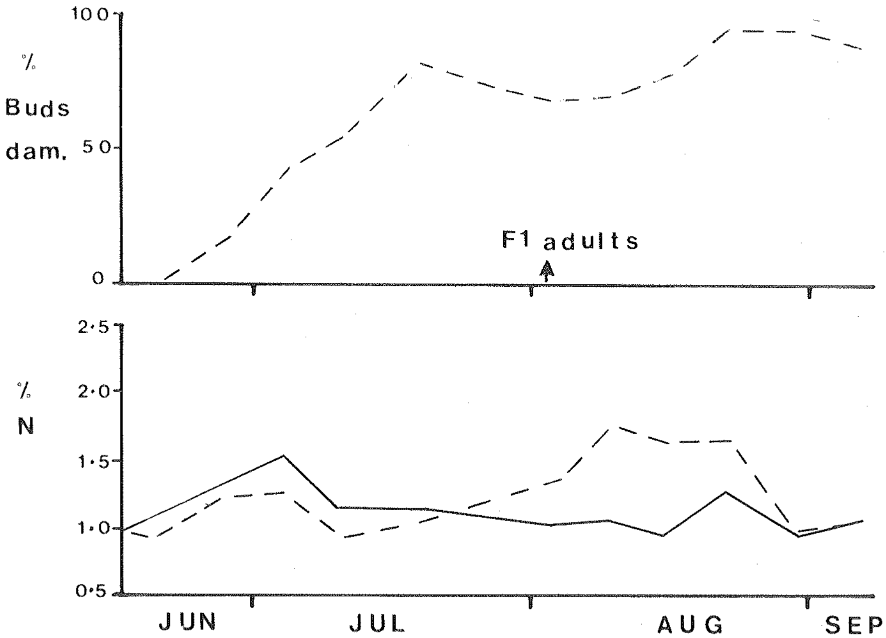

Fig. 1. Percent of buds damaged and % nitrogen dry weight in *Salvinia molesta* D.S. Mitchell with (– –) and without (—) attack by *Cyrtobagous salviniae* Calder & Sands.

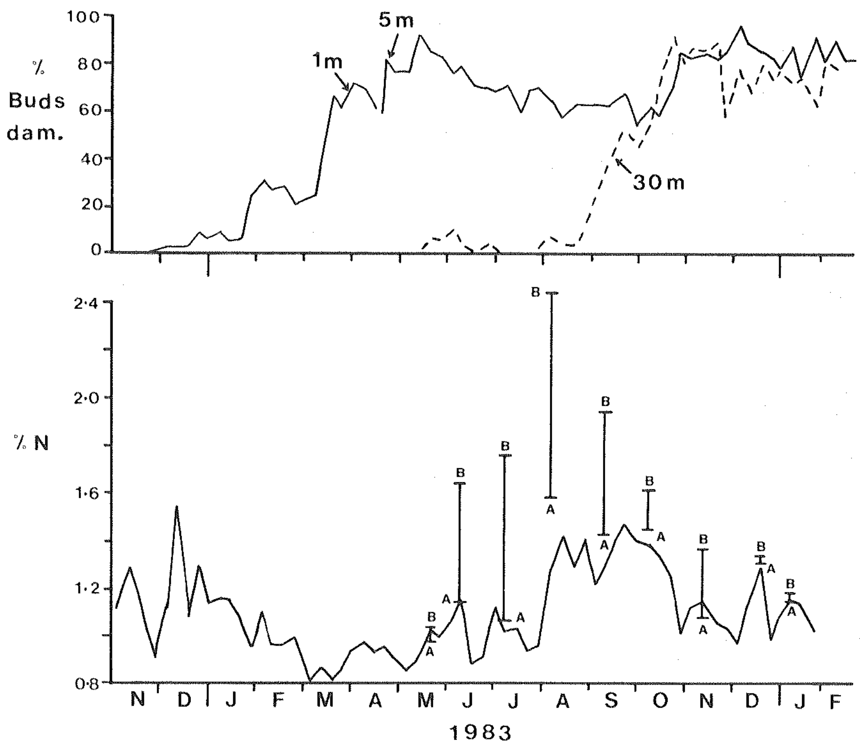

Fig. 2. Percent of buds damaged 1, 5 and 30 m from the cages in Binatang Lagoon and % nitrogen dry weight 30 m from the cages (continuous line and A) and 5 m from the cages (B). Continuous line: samples of four youngest nodes/plant; A & B: samples of two youngest nodes/plant.

region, establishment has taken from three to nine months, with an average of about five months. The Gerehu release of 107 adults has been the smallest number of adults to have established in PNG. It is not known whether such a low number would suffice under the lower nutrient conditions in the Sepik.

Effects of *Cyrtobagous salviniae*

The performance of *C. salviniae* has varied considerably according to the nature of the salvinia infestations. In Binatang Lagoon, the insects moved away from the cages in a 'wave' (Fig. 2). The population close to the cages peaked in May 1983, then decreased, presumably as adults dispersed in search of food. This allowed damaged salvinia to regenerate to some extent and the insect population built up once more. In November 1983 there was another peak of activity both close to and further from the cages. Adult numbers reached *c.* 20/kg salvinia, with bud damage at *c.* 90%. Routine samples were only taken up to 30 m from the cages but it was apparent that insects were present on open mat through at least 75% of the lagoon. There was no indication of significant attack on salvinia which had been colonised by sudd vegetation. By May 1984 insects were present throughout the lagoon, open mats of salvinia had disappeared and sudd islands covered no more than 50% of the water surface.

Gerehu Lake provides an even more extreme example of the apparent reluctance of *C. salviniae* to disperse. In December 1983, 10 months after release, the insects had caused a well-defined patch of damage up to 20 m from the release site. Most of the damaged material was waterlogged and rotting, being held afloat only by the compaction of the very thick mat. No sign of insect activity could be found beyond 5 m from the obvious 'invasion front'. The complete immobility of the weed mat and its unusual thickness presumably ensured that the expanding insect population was continually presented with a fresh food supply. A similar development has occurred on Panau Lagoon in the Sepik region where three separate releases on a thick, stationary mat, have resulted in three discrete patches of *C. salviniae* damage. Room *et al.* (1984) report the same phenomenon from a very thick mat at Kaban in Australia.

The 370 ha Imbuando Lagoon presents a complete contrast to the sites discussed above. In May 1983, when salvinia cover was 80%, 15,000 adult *C. salviniae* were released into the centre of the open mat. By September 1983, mainly as a result of a cycle of partial flushing and regeneration, cover had fallen to 50% and the weed mat was extremely mobile. Low level *C. salviniae* damage was present throughout the lagoon. From September onwards the river began to rise, precluding any further significant flushing. By the beginning of November, bud damage had reached 50% and one month later exceeded 90% through the whole weed mat. Since that time the mat has turned progressively brown and has sunk. By May 1984 the lagoon was completely clear of salvinia with the exception of small, damaged plants confined to the marginal emergent vegetation. Most of the other sites in the Sepik region where *C. salviniae* has established appear to be following a similar pattern.

Discussion

Experience in the Sepik region suggests that *C. salviniae* will perform best on single layer, mobile weed mats. The insects rapidly become evenly distributed by movement of the weed mat resulting in uniform damage over the whole lagoon. Consequently, when food availability falls, the insects have nowhere to go and a high level of feeding pressure is maintained, resulting in destruction of the weed mat. In Imbuando, this pressure has become so great that the small sudd islands in the lagoon have also been destroyed. Whether or not this will happen in lagoons such as Binatang remains to be seen.

Reasons for avoidance by *C. salviniae* of sudd islands are not clear. Preliminary results suggest that thicker mats, whether or not colonised by sudd plants, are lower in N than thin mats from the same lagoon. This could be a result of increased competition and difficulties of root contact with water. On Gerehu Lake, with an average N level of 1.58% as opposed to 1.06% for Binatang, mat thickness may have been offset by greater availability of nutrients.

The ideal situation for the Sepik region would be destruction of weed mats in open water, leaving a residual *C. salviniae* population in a thin fringe of salvinia growing among marginal vegetation. Imbuando Lagoon is now at this stage and others are approaching it. Lagoons which have very heavy sudd cover may require initial treatment with herbicide. Regrowth would then consist of small, mobile mats, relatively rich in nutrients released from decaying, sprayed plants, and would provide ideal conditions for *C. salviniae*.

Until now, the major problem with salvinia management has been the need for costly, repetitive spraying to deal with regrowth from the few inevitable survivors of a herbicidal control programme. *C. salviniae* appears to have the potential to be the major component of integrated programmes for management of both established, previously intractable, salvinia infestations and new infestations at greatly reduced cost.

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Disclaimer

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